STRUCTURE AND FUNCTION OF SMALL, HEADWATER STREAMS FLOWING THROUGH WET EUCALYPT FOREST IN SOUTHERN TASMANIA AND THE IMPACT OF CLEARFELL FORESTRY

by

RYAN MITCHELL BURROWS

BSc (Hons), University of Western Australia, 2007

Submitted in fulfilment of the requirement for the degree of

Doctor of Philosophy

University of Tasmania (February 2013)

Declaration of originality

I hereby declare that this thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

5th February 2013

Ryan Burrows Date

Authority of access

This thesis may be made available for loan and limited copying and communication in accordance with the *Copyright Act* 1968.

Statement regarding published work contained in this thesis

The publishers of the papers comprising Chapters 2 to 4 hold the copyright for that content, and access to the material should be sought from the respective journals. The remaining non published content of the thesis may be made available for loan and limited copying and communication in accordance with the *Copyright Act* 1968.

5th February 2013

Ryan Burrows Date

Statement of publications

Manuscripts (published or submitted to peer-reviewed journals) produced as part of this thesis:

(1) **Burrows, R. M.**, Magierowski, R. H., Fellman, J. B., and Barmuta, L. A. 2012, Woody debris input and function in old-growth and clear-felled headwater streams. *Forest Ecology and Management*, 286: 73-80.
(2) **Burrows, R. M.**, Fellman, J. B., Magierowski, R. H., and Barmuta, L. A. 2013, Greater phosphorus uptake in forested headwater streams modified by clearfell forestry. *Hydrobiologia*, 703: 1-14.
(3) **Burrows, R. M.**, Fellman, J. B., Magierowski, R. H., and Barmuta, L. A. 2013, Allochthonous dissolved organic matter controls bacterial carbon production in old-growth and clearfelled headwater streams. *Freshwater Science*, 32(3): DOI: 10.1899/12-163.

Statement of Co-Authorship

The following people and institutions contributed to the publication of work undertaken as part of this thesis:

Ryan M. Burrows (University of Tasmania) was the lead author of the three papers and contributed to all aspects of each study including the development of ideas, the collection and analysis of data, and the writing of the manuscript.

Leon A. Barmuta (University of Tasmania) assisted with guidance and supervision of the research relating to the development of ideas, data collection, statistical analysis, interpretation of results, and producing publishable manuscripts of (1), (2), and (3).

Regina H. Magierowski (University of Tasmania) assisted with guidance and supervision of the research relating to the development of ideas, data collection, statistical analysis, interpretation of results, and producing publishable manuscripts of (1), (2), and (3).

Jason B. Fellman (University of Western Australia and University of Alaska Southeast) assisted with guidance and supervision of the research relating to the data preparation, statistical analysis, interpretation of results, and producing publishable manuscripts of (1), (2), and (3).

We, the undersigned, agree with the above stated "proportion of work undertaken" for each of the above published (or submitted) peer-reviewed manuscripts contributing to this thesis:

Signed: ___________________ ________________________

Leon Barmuta	***Elissa Cameron***
Supervisor	***Head of School***
School of Zoology	***School of Zoology***
University of Tasmania	***University of Tasmania***

Date:______________________ ______________________

Statement of communications

Conference proceedings in which I was the primary presenter as part of this thesis:

Burrows, R. M., Fellman, J. B., Magierowski, R. H., and Barmuta, L. A. 2011, Increased phosphorus retention in Tasmanian headwater streams modified by clearfell, burn and sow forestry. *Abstracts of the 50th Annual Congress of the Australian Society of Limnology (ASL) with the New Zealand Freshwater Science Society (NZFSS)*, Brisbane, Australia.

Burrows, R. M., Fellman, J. B., Magierowski, R. H., and Barmuta, L. A. 2011, Increased phosphorus retention in Tasmanian headwater streams modified by clearfell, burn and sow forestry. *Abstracts of the Ecological Society of Australia Annual Conference*, Hobart, Australia.

Burrows, R. M., Fellman, J. B., Magierowski, R. H., and Barmuta, L. A. 2012, Greater phosphorus uptake in forested headwater streams modified by clearfell forestry. *Abstracts of the CRC for Forestry Annual Science Meeting*, Sunshine Coast, Australia.

Burrows, R. M., Fellman, J. B., Magierowski, R. H., and Barmuta, L. A. 2012, Greater phosphorus uptake in forested headwater streams modified by clearfell forestry. *Abstracts of the Society of Freshwater Science Annual Meeting*, Louisville, U.S.A.

Burrows, R. M., Fellman, J. B., Magierowski, R. H., and Barmuta, L. A. 2012, Allochthonous dissolved organic matter controls bacterial carbon production in forested, headwater streams. *Abstracts of the Tasmanian Australian Society of Limnology (ASL) Forum*, Hobart, Australia.

Abbreviations

AFDM	Ash-free dry mass
AICc	Akaike's Information Criterion adjusted for small sample size
ANCOVA	Analysis of covariance
ANOSM	Analysis of similarity
ANOVA	Analysis of variance
BA	Before-after
BCP	Bacterial carbon production
C	Carbon
C1	Component 1
C2	Component 2
C3	Component 3
CBS	Clearfell, burn and sow
CDP	Cellulose decomposition potential
CI	Control-impact
CPOM	Coarse particulate organic matter
CTFL	Cotton tensile force loss
CTFR	Cotton tensile force ratio
DIN	Dissolved inorganic nitrogen
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DON	Dissolved organic nitrogen
DOP	Dissolved organic phosphorus
EEMs	Excitation-emission matrices
FI	Fluorescence index
FPOM	Fine particulate organic mater
FWD	Fine woody debris
GLA	Gap Light Analyzer
ha	Hectare
HCL	Hydrochloric acid
IBRA	Interim Biogeographic Regionalisation for Australia
LAI	Leaf area index
LMM	Linear mixed-effects model
LWD	Large woody debris
m asl	Meters above sea level
MBACI	Multiple before-after control-impact
MEZ	Machinery exclusion zone
N	Nitrogen
NH_3	Nitrate
NH_4	Ammonium
nMDS	Non-metric multidimensional scaling

OG	Old-growth
OM	Organic matter
P	Phosphorus
PARAFAC	Parallel factor analysis
PERMANOVA	Permutational multivariate analysis of variance
PERMDISP	Permutational analysis of multivariate dispersions
SRP	Soluable reactive phosphorus
SUVA	Specific ultra-violet absorbance
S_w	Uptake length
TCA	Trichloroacetic acid
TDN	Total dissolved nitrogen
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSH	Time since harvest
TSR	Tasmanian Southern Ranges
U_f	Uptake rate
UV	Ultra-violet
UVA	Ultra-violet radiation
V_f	Uptake velocity
VIS	Visable
Wt	Weight

Acknowledgments

First and foremost I would like to thank my supervisors, Associate Professor Leon Barmuta and Dr. Regina Magierowski, for their support and guidance over the years. Without your energy and enthusiasm for freshwater ecosystems this project would not have been possible. I would also like to thank my research advisor, Dr. Jason Fellman, who has provided advice and guidance from afar in both Western Australia and Alaska. The words in this thesis are just a fraction of the knowledge that you have all shared with me, but they have culminated into this body of work which I am very proud of.

Thanks to Chris Spencer from the Tasmanian Forest Practices Authority (FPA) for the many weeks spent in the field with me. Your local knowledge of Tasmanian flora and fauna, forest practices, and leach removal was invaluable. Thank you to Dr. Jean Jackson for teaching me how to operate the study weirs and insert cotton strips into benthic sediment. Thanks also to Dr. Joanne Clapcott for your role in initiating the MBACI headwater streams project and to Laurie Cook for collecting the data when no one else could.

A special thanks for all those volunteers who helped my find study sites, collect water samples, measure woody debris, and conduct experiments: K. Hawkes, J. Delaine, E. Polymeropoulos, T. Hollings, J. Haag, J. Fountain, S. Griffin, A. Brüniche-Olsen, J. Kramer, J. Goon, K. Kreger, M. Burrows, B. Burrows, A. Watson, and L. Quayle. Without your help through rain, hail, snow, and sunshine this fieldwork would not have been possible!

I am indebted to all the Forestry Tasmania staff that assisted me through this journey. In the Hobart office I'd like to thank Dr. Sandra Roberts for your feedback regarding the management implications of my research and Dr. Crispen Marunda for providing me with the best possible estimates of sub-catchment boundaries. A huge thanks to all those in the Huon district office, especially Cath and Matt, for providing the right gate keys and ensuring that I was always home safe at the end of each day.

Thanks to all the staff at FPA who assisted me over the years, including Dr. Sarah Munks who always provided me with the support that I required. A large part of this thesis would not have been possible if it was not for the in-kind support of this organisation.

Thank you to all the staff, academics, and fellow postgraduates at the School of Zoology who have made me feel welcome and kept my project running like a well-oiled machine. In particular I'd like to thank Richard Holmes for all the equipment repairs and ideas; Wayne Kelly for the IT and laboratory support; Kate Hamilton and Adam Smolenski for the laboratory equipment and support; Adam Stephens and Simon Talbot for organising vehicles and attempting to unravel the OH&S procedures of Zoology and UTAS; Barry Rumbold for all the financial thumbs up; Felicity Wilkinson for simply being the best secretary ever; and Chris Burridge for the footy tips. I cannot thank my fellow postgraduate students enough for the support, encouragement, ideas, food, beer, and fun times you have all provided and shared me.

I would like to thank my Washington and Cartela housemates over the years: Tracey Hollings, Elias Polymeropoulos, Martin Wæver Pedersen, Judith Fernandez, Lydie Lescarmontier, Jon DeLaine, Alex Stedman, Bandit, and Steal – I could not have asked for better friends and hounds!

To my family and friends, thank you for supporting and encouraging me throughout this adventure. Even though many of you were on other side of the country, none of this would have been possible without your love and support. Finally, thanks to Kris for your immense emotional and financial support, patience, encouragement, and love throughout the years. I cannot guarantee that I won't still require these after this thesis is finalised!

This thesis was supported by a range of funding bodies. My Postgraduate Scholarship was funded by the University of Tasmania, School of Zoology, and the CRC for Forestry. Financial support for research included: a Student Grant from the Tasmanian Forest Practices Authority; Holsworth Wildlife Research Endowment; Maxwell Ralph Jacobs Fund of The Institute of Foresters of Australia; and a Warra Grant from Forestry Tasmania. In-kind support was provided by FPA and Forestry Tasmania. I sincerely thank all of you for your generous contributions.

Holsworth Wildlife
Research Endowment

Abstract

Clearfell, burn and sow (CBS) forestry is a major disturbance to headwater streams flowing through wet eucalypt forests in southern Tasmania involving clearfelling trees around them and the burning of remaining slash within a year of harvest. The aim of this research was to assess the short-term (<19 years) effects of CBS forestry on several key structural (woody debris and dissolved organic matter source and composition) and functional (nutrient uptake and organic matter processing) characteristics of headwater streams in southern Tasmania. I evaluated these using a combination of replicated space-for-time surveys and an MBACI (multiple before-after control-impact) experiment in headwater stream reaches flowing through old-growth and CBS-affected forest.

My findings show that CBS forestry increased available light, elevated water temperatures (between 0.25 and 0.94°C), and significantly increased the quantity of woody debris situated in the stream channel. I also used fluorescence characterisation of dissolved organic matter (DOM) to show that forest harvesting did not affect the relative contributions of autochthonous and allochthonous stream DOM despite the major reach-scale disturbance that clearfell forestry represents. However, there was conflicting evidence for changes in DOM composition after harvesting. It is likely that catchment-scale processes are more important than reach-scale processes (i.e. forest harvesting) in determining stream DOM biogeochemistry, because only a small proportion of the total channel length (<100 m) is affected by clearfell forestry.

The large physical structural changes to headwater streams caused by CBS forestry led to changes in stream function. Nutrient addition experiments showed greater phosphorus uptake in CBS-affected relative to old-growth (OG) stream reaches, which was likely due to increased biotic activity (algae and bacterial biofilms) related to greater in-stream light availability and quantity of in-stream

woody debris. However, sorption to sediment and charred woody debris may also have contributed to the greater phosphorus uptake after harvesting. The impact of CBS forestry on organic matter decomposition differed among years and benthic habitats, with evidence for an increase in bacterial carbon production (BCP) in fine sediment habitat but a decrease in BCP and cellulose decomposition in coarse gravel habitat. Contrary to most previous research, increasing contribution of terrestrial DOM was the strongest variable driving in situ benthic BCP.

Some of the structural changes from CBS may be beneficial in reducing impacts at the catchment-scale. For instance, the observed increase in the amount of woody debris and light availability after harvesting may prevent elevated phosphorus export to downstream ecosystems by increasing phosphorus uptake and retention in headwaters. While these effects characterised the short-term responses to CBS in these headwater streams, the longer-term (>19 years) and catchment-scale impacts require further research. Many variables (e.g. the quantity of woody debris) will take decades to recover to pre-disturbance levels and the cumulative impacts of harvesting multiple coupes throughout the landscape needs to be determined to ensure that CBS operations are managed in space and time to minimise impacts on downstream ecosystems.

Table of Contents

List of Figures